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Simulation of Fuel Ignition Delay in Diesel Engines with Various Fuel Feeding Systems

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Abstract

A mathematical model for numerical simulation of the fuel combustion delay in a diesel engine as a problem of dynamic thermal explosion during the adiabatic compression has been established. Ignition of fuel and air mixture in the local volume is considered at simultaneous evaporation of drops and gas chemical reaction within overall kinetics. Satisfactory correlation of computation and experimental fuel combustion delays on speed ability and load ability of the diesel is obtained. Numerical modeling of ipact of general kinetics constants on the fuel combustion delay is carried out. The features of self-ignition in the diesel are considered at low values of chemical reaction activation energy.

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Keywords: Diesel; fuel; combustion delay; spontaneous ignition; chemical reaction; overall kinetics constants.

1. Introduction

The fuel combustion delay in the diesel is the important characteristic of the working process which knowledge is necessary at the engine design stage. Combustion delay is measured experimentally on the test diesel or calculated with the empirical equations which usually look like the equation of O.M. Todes for the induction period of the adiabatic thermal explosion (TE) [1, 2]

$$\tau_i = Bp_1^n \exp\left(E/RT_1\right) , \tag{1}$$

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where B, n are empirical coefficients; p_1, T_1 pressure and temperature at the time of the beginning of the fuel injection, corresponding to a crank angle (CA) $\phi = \phi_1$; E - activation energy of overall reaction of fuel ignition; R - universal gas constant. We note that these empirical equations have the insufficient accuracy and limited application. We note that these empirical equations (1) have the insufficient accuracy and limited application.

It is known that the working body in the diesel ignites from compression therefore the considered problem belongs to the TE dynamic modes. In the assumption of the homogeneous working body, the problem of combustion delay in the diesel, on the basis of results of work [3], apparently, for the first time in the theoretical plan is solved in works [4, 5]. As a result of the analysis it is obtained, for the sinus mechanism $V = V_c + rF_p(1 - \cos\phi)$ the condition of self ignition for critical pressure $P^* = p^*/p_1$ in the system (for range of pressure $P^* < P_{\max}$):

$$\frac{(Q/C_P T_1) k_0 (p_1/RT_1)^{s-1} (P^*)^{(s-1)/\gamma - 1}}{2\pi n_0 \left[1 + \alpha\left(1/a_f^\circ - 1\right)\right]^s \sqrt{\left(\frac{\varepsilon}{\varepsilon_1} - (P^*)^{-1/\gamma}\right)\left((P^*)^{-1/\gamma} - \frac{1}{\varepsilon_1}\right)}} \exp\left[\frac{E}{RT_1}(P^*)^{1/\gamma - 1}\right] = \frac{1}{\mathrm{e}}, \qquad (2)$$

$$\tau_i = \frac{\Delta\phi^*}{2\pi n_0} = \frac{\phi^* - \phi_1}{2\pi n_0} = \frac{1}{2\pi n_0}\left(\arccos\frac{\varepsilon + 1 - 2\varepsilon_1 (P^*)^{-1/\gamma}}{\varepsilon - 1} - \phi_1\right), \qquad P_{\max} = \frac{p_{\max}}{p_1} = \varepsilon_1^\gamma,$$

where V_c - volume of combustion chamber; $F_p = \pi D^2/4$ - piston area; r - crank radius; e =2,71828..; $\varepsilon = 1 + 2rF_p/V_c$ - geometric compression ratio; ε_1 - compression ratio after CA $\phi = \phi_1$; n_0 - crankshaft frequency; α - air excess coefficient; a_f° - stoichiometric concentration of fuel in the homogeneous mixture with air; k_0, s - pre-exponential factor of the rate constant and total order of chemical reaction of self ignition; $\gamma = C_P/C_V$ - ratio of thermal capacities; Q - molar heat release of the fuel. Subscript “1” applies to the time of the fuel injection beginning.

Despite simplicity of the mathematical model offered in [4, 5], the analytical solution of the problem on critical condition of mixture self ignition due to compression (2) obtained reflects correctly physical and chemical processes of fuel ignition in the diesel and even it may be recommended to practical use.

However real process of ignition in the diesel is much more difficult than process of ignition of a homogeneous mixture at adiabatic compression. We will formulate the specified mathematical model which some hypotheses are presented in [6, 7].

2. Mathematical model for the local volume

We believe that the rational problem definition may be based that the diesel torch is ignited with some self-ignited local volume (LV) that is located near an external surface of the fuel jet [6, 7]. This LV is formed practically at the time of the beginning of fuel injection $\phi = \phi_1$ from the smallest drops evaporating in the course of further compression. The problem is reduced to finding of the ignition delay (the induction period) τ_i of this LV.

In addition for LV we accept:

1. the drops which are in LV evaporate due to internal energy of LV which further up to self ignition doesn't exchange energy and mass with surrounding gas and other drops which are both out of and in the fuel torch;
2. only one LV is formed that doesn't reduce a problem generality (as it is possible to change initial conditions of self ignition in this LV);
3. we suppose that drops in LV at the moment $\phi = \phi_1$ instantly heat up from fuel supply temperature T_f to boiling temperature T_s due to internal energy of LV and then gradually evaporate and self ignition occurs in gas phase of LV.